Designing Experimental Exercises Used for Teaching Chemistry in High School

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Abstract This study has represented a model of experimental exercises in teaching chemistry. The model, which is the type of exercise associated with chemistry laboratories that when students answer them, they have to get the basic skills of practice chemistry. By analyzing the model of experimental exercises, we have proposed two underpinnings to design these exercises. On that basic, we proposed the way to design new experimental exercises. These methods are analyzed in detail and there are the attached application so that teacher can apply to design the same cases. Based on the proposed methods, we have designed sample exercises used in high school chemistry teaching. The exercises were solved clearly and evaluation of chemistry practical skills for students. This type of exercises is always attractive to create certain excitements for teachers and students in the teaching and learning chemistry in high school.

Keywords: teaching chemistry, experimental exercises, chemistry practical skills, laboratory


1. Introduction

1.1. Model of Experimental Exercises of Chemistry

Chemistry experimental exercises are problems that students have to apply their practised knowledge in the laboratory when they answer them. Model of experimental exercises below.

![Experimental Exercise Diagram]

- **conditions**: 1/ The thinking activities, 2/ The practical skills in lab
- **requirements**: Data about chemistry practices (Given), Requirements on chemistry practice (Unknown)

1.2. Underpinnings of Designing Chemistry Experimental Exercises

From the model above, we inferred 2 underpinnings for designing practical exercises of chemistry [1].

**Theoretical underpinning**: including the contents of chemistry theory [2].

**Experimental underpinning**: including the experimental contents and practicing skills in the lab [3].

Thus, in order to design experimental exercises may stem from:

1. The basic knowledge and practicing skills to train for students [4].
2. Common mistakes of theory and practice that students often make.
3. Some basic exercises available.

Based on the underpinnings and the starting point above, we can build an chemistry experimental exercise with typical basic properties (called as the original exercise). Applying grap method combined with the modular approach, we can modify the original exercise into some different exercises based on some fundamental principles below.

Principle 1: Inverse between conditions and requirements  
Principle 2: Change conditions  
Principle 3: Change requirements  
Principle 4: Change both conditions and requirements  
Principle 5: Combination several exercises  
Principle 6: Transfer essay exercises (short answer or extended response) to multiple choice test and vice versa.

2. Method - Designing Exercises

We can consider an example for teaching halogen chapter of inorganic chemistry. After students have completed this chapter, teachers should check students’ practical skills of collecting chlorine gas in the laboratory. Teachers can build the following original exercise.
Original exercise: In the laboratory, chlorine gas is often prepared from MnO₂ and concentrated HCl acid [5].

a) Write the chemical equation for this reaction.
b) Was chlorine gas obtained above pure or not?

In this exercise, teachers can test students’ knowledge about the preparation and collecting of dry chlorine gas in lab. The chemical equation for the reaction is shown below.

\[
\text{MnO}_2(s) + 4\text{HCl}(\text{conc.}) \xrightarrow{\text{heat}} \text{MnCl}_2(\text{aq}) + \text{Cl}_2(\text{g}) + 2\text{H}_2\text{O}(l)
\]

From the equation, students will recognize the obtained chlorine gas is not pure because of containing a small amount of hydrogen chloride gas and water vapor.

Applying in turn 6 principles above, at least we can design 6 derivative exercises stem from the original exercise [8]. For example:

Apply principle 1: In laboratory, chlorine gas is formed from the following reaction

\[
\text{MnO}_2(s) + 4\text{HCl}(\text{conc.}) \xrightarrow{\text{heat}} \text{MnCl}_2(\text{aq}) + \text{Cl}_2(\text{g}) + 2\text{H}_2\text{O}(l)
\]

If chlorine gas prepared directly from the reaction, product is not pure. Give an explanation.

Apply principle 2: In the laboratory, chlorine gas is often prepared from MnO₂ and conc. HCl acid. Sometimes, we need to use a dry gas in an experiment. To collect clean and dry chlorine gas, obtained gas can go through the gas washing bottles A and B (Figure 1). Which substance will the gas washing bottles A and B contain in the following substances: Ca(OH)₂ solution, NaOH solution, NH₃ solution, NaCl solution, Br₂ solution, conc. H₂SO₄ acid and H₂O? Explain that choice.

Solution: Obtained gases consist of chlorine, hydrogen chloride and water vapor. We infer the gas washing bottle A containing NaCl solution (removing hydrogen chloride) and the gas washing bottle B containing conc. H₂SO₄ acid (drying agent).

Apply principle 3: In the laboratory, chlorine gas is often prepared from MnO₂ and conc. HCl acid. Sometimes, we need to use a dry gas in an experiment. To collect clean and dry chlorine gas, obtained gas can go through the gas washing bottles A and B (Figure 1). Which substance will the gas washing bottles A and B contain in the following substances: Ca(OH)₂ solution, NaOH solution, NH₃ solution, NaCl solution, Br₂ solution, conc. H₂SO₄ acid and H₂O? Explain that choice.

Solution: In this exercise, requirements have been complicated, students will write the chemical equation for the reaction below.

\[
\text{MnO}_2(s) + 4\text{HCl}(\text{conc.}) \xrightarrow{\text{heat}} \text{MnCl}_2(\text{aq}) + \text{Cl}_2(\text{g}) + 2\text{H}_2\text{O}(l)
\]

Students deduce the gas products containing a small amount of hydrogen chloride gas and water vapor. So the flask B is used for washing gas, the flask C is used for drying gas, the flask D is used for collecting gas and the flask E is used for eliminating residual chlorine gas.
b) From features of the above flasks, indicating laboratory apparatuses are not reasonable:
- The tube introducing the gas from the flask A has to immerse deeply in the NaCl solution (inside flask B) so that hydrogen chloride gas is readily soluble in salt solution. Second delivery tube of flask B has to be shorter placed and not touch the NaCl solution so that chlorine gas goes into flask C easily and not push NaCl solution into the flask C.
- Similarly, left delivery tube of the flask C has to immerse deeply in H₂SO₄ solution (removing water vapor) and right delivery tube has to be shorter placed (not touch the H₂SO₄ acid) so that chlorine gas goes into flask D easily and H₂SO₄ solution is not pushed into the flask D.
- The left delivery tube of the flask D has to be designed longer than the right delivery tube because it only has a task that is treatment the residual chlorine gas in the flask D when it was fully collected.
The apparatus should be set up as Figure 4 below.

Apply principle 5: In the laboratory, the apparatus is installed to prepare and collect C gas as shown in Figure 5. The flask A in which contained solid and the funnel B contained liquid.
a) Indicate C gas is denser or less dense than air?
b) What is the gas C if A is MnO₂ and B is conc. HCl acid?
c) Explain the phenomenon that occurs when the lock K closed and opened.
d) How to remove a residual C gas in the lab? Write the chemical equation if available.

Apply principle 6: To collect the chlorine gas in the laboratory, which can you do in the following ways?
A. Collecting directly by means of pushing the air.
B. Collecting over hot water.
C. Collecting over saturated NaCl solution.
D. All 3 ways of the above.
Solution: In this exercise, in spite of the objective test, but students want to answer this exercise, they have to know the properties of chlorine gas, namely:
- Chlorine gas is denser than air, it can be collected directly by displacement of air with downward delivery.
- Chlorine gas is less soluble in hot water, because the following equilibrium shifts to the left:

\[
2\text{Cl}_2(g) + 3\text{H}_2\text{O}(l) \rightleftharpoons \text{HCl}(aq) + \text{HClO}(aq)
\]

In a saturated NaCl solution, chlorine gas is also very slightly soluble so the above equilibrium shifts to the left.
Thus all three methods will be able to collect chlorine gas (Answer D).

Test Yourself
1. Which gases was the apparatus shown used to collect in the laboratory [8]?
   A. Cl₂, O₂ and CO₂
   B. Cl₂, O₂ and NH₃
   C. CO₂, NO and NH₃
   D. Cl₂, O₂, NO, CO₂ and NH₃
   Answer A.
2. Which gases was the apparatus shown used to collect in the laboratory?
   A. CO₂ and H₂
   B. NH₃ and H₂
   C. CO₂ and NO₂
   D. NO₂ and NH₃

Answer B.

3. Which gases was the apparatus shown used to collect in the laboratory?
   A. O₂ and NH₃
   B. NO and HCl
   C. NH₃ and HCl
   D. O₂ and NO

Answer D.

4. In the laboratory for the preparation and collection of some pure gases, people set up experimental kits as shown below.

Flask (A): Containing liquid or solution.
Flask (B): Containing solid or solution.
Flask (C): Containing liquid or solution.
Flask (D): Containing solution or solid (Tisenco Flask).
Flask (E): Collecting gas.

Above apparatus can be used to prepare and collect which gases of the following gases?
   A. Cl₂, HCl, H₂S, SO₂, NO₂, CO₂
   B. SO₂, NO₂, NH₃, CO, CO₂
   C. HCl, H₂S, SO₂, NO₂, CH₄
   D. O₂, Cl₂, H₂, HCl, H₂S

Answer A.

5. Figure below simulated image was observed when the A gas passes through a gas washing bottle containing B liquid.

   A and B substances in the experiment above is
   A. A is NH₃, B is H₂O
   B. A is HCl, B is C₂H₅OH
   C. A is CH₄, B is H₂O
   D. A is O₂, B is H₂O

Answer A.

6. Carry out an experiment as shown below: Flask contains A gas inserted a delivery tube into the beaker containing B liquid. When unlocked K, liquid of B sprayed into the flask. If liquid B is the solution Br₂ in CCl₄ which gas is A gas in the following gases?
   A. SO₂
   B. C₂H₄
   C. H₂S
   D. NH₃

Answer B.

7. A student set up the apparatus to prepare hydrogen gas by Kipp gas generator in the laboratory as shown below.

Observation on the above apparatus can indicate how many mistakes made hydrogen gas can not be collected in a laboratory?
   A. 1
   B. 2
   C. 3
   D. 4

Answer B.
8. In the laboratory, carbon dioxide gas is often prepared from CaCO\textsubscript{3} and HCl acid (the following figure) thus containing a small amount of hydrogen chloride gas and water vapor.

To collect pure carbon dioxide gas, product can be gone through 2 flasks (A) and (B) contain which substances in the following substances?

A. Vessel (A) contains NaHCO\textsubscript{3} solution and vessel (B) contains conc. H\textsubscript{2}SO\textsubscript{4} acid.
B. Vessel (A) contains conc. H\textsubscript{2}SO\textsubscript{4} acid and vessel (B) contains NaHCO\textsubscript{3} solution.
C. Vessel (A) contains NaHCO\textsubscript{3} solution and vessel (B) contains conc. HNO\textsubscript{3} acid.
D. Vessel (A) contains conc. HNO\textsubscript{3} acid and vessel (B) contains NaHCO\textsubscript{3} solution.

Answer A.

9. In the laboratory, chlorine gas is often prepared from MnO\textsubscript{2} and conc. HCl acid. To collect clean and dry chlorine gas, obtained gas can go through the gas washing bottles A and B as shown below. Which substance will the gas washing bottles A and B contain in the following substances?

A. Vessel (A) contains Ca(OH)\textsubscript{2} solution and vessel (B) contains NH\textsubscript{3} solution.
B. Vessel (A) contains Ca(OH)\textsubscript{2} solution and vessel (B) contains conc. H\textsubscript{2}SO\textsubscript{4} acid.
C. Vessel (A) contains KMnO\textsubscript{4} solution and vessel (B) contains conc. H\textsubscript{2}SO\textsubscript{4} acid.
D. Vessel (A) contains conc. H\textsubscript{2}SO\textsubscript{4} acid and vessel (B) contains KMnO\textsubscript{4} solution.

Answer C.

10. There are 3 students who carry out to prepare O\textsubscript{2} by pyrolysis reaction of potassium permanganate in the test tube which is set up as shown below (a, b, c).

The way to set up the test tube in according to which figure is correct?

A. a)
B. b)

Answer C.

11. To collect pure nitrogen gas from the gas mixture of N\textsubscript{2}, O\textsubscript{2}, CO, CO\textsubscript{2} and water vapor, the gas mixture passes in turn through the substances A, B, X and Y, as shown below.

The substances A, B, X and Y are respective

A. Cu, CuO, NaOH soln. and conc. H\textsubscript{2}SO\textsubscript{4} acid.
B. Cu, CuO, conc. H\textsubscript{2}SO\textsubscript{4} acid and NaOH soln.
C. CuO, Cu, NaOH soln. and conc. HCl acid.
D. CuO, Cu, conc. HCl acid and NaOH soln.

Answer A.

12. There are 3 gases (N\textsubscript{2}, H\textsubscript{2}S, HCl) contained in 3 test tubes which were turned upside-down in 3 water baths as shown below.

Gas in the test tubes which were turned upside down in 3 water baths X, Y, Z respectively

A. N\textsubscript{2}, H\textsubscript{2}S, HCl
B. HCl, H\textsubscript{2}S, N\textsubscript{2}
C. H\textsubscript{2}S, HCl, N\textsubscript{2}
D. HCl, N\textsubscript{2}, H\textsubscript{2}S

Answer B.

13. The apparatus shown was used to collect a dry gas.

The substances X and Y are respective

A. conc. H\textsubscript{2}SO\textsubscript{4} acid and NH\textsubscript{3}
B. conc. H\textsubscript{2}SO\textsubscript{4} acid and CO\textsubscript{2}
C. H\textsubscript{2}O and CO\textsubscript{2}
D. H\textsubscript{2}O and NH\textsubscript{3}

Answer B.

14. In the laboratory, chlorine gas is often prepared from MnO\textsubscript{2} and concentrated HCl acid [5]. To collect clean and dry chlorine gas, obtained gas can go through the gas washing bottles containing X and Y solution as shown below.
The solutions of X and Y are respectively
A. saturated NaCl soln. and conc. H₂SO₄ acid
B. NaOH soln. and conc. H₂SO₄ acid
C. conc. H₂SO₄ acid and saturated NaCl soln.
D. conc. H₂SO₄ acid and NaOH soln.
Answer A.

15. The apparatus is installed to test solubility of a gas as shown below [13]. In downward gas flask, pink water sprayed onto can be seen. Gas in the flask is

A. HCl
B. NH₃
C. H₂S
D. N₂
Answer B.

16. In the experiment below, fresh chlorine gas, which was prepared from solid manganese dioxide and concentrated hydrochloric acid solution, passed into a cylindrical tube with a piece of color paper.

Which of the following statements is true?
A. When the K is closed, the color paper will lose its color, when K is unlocked, the color paper will not lose its color.
B. When the K is closed, the color paper is not discolored, when K is unlocked, the color paper becomes discolored.
C. When K is unlocked, the color paper turns pink.
D. When K is unlocked, the color of the paper does not change.
Answer B.

17. The following figure describes the experiment to prepare metal by using hydrogen gas to reduce metal oxide [9,10,11].

X appropriate oxides may be
A. MgO and K₂O.
B. Fe₂O₃ and CuO.
C. Na₂O and ZnO.
D. Al₂O₃ and BaO.
Answer B.

18. Vapour of alcohol X is passed through a porcelain tube containing powder of CuO heated as the shown figure below [12].

Two alcohols not satisfied with the properties of X are
A. ethanol and propan-1-ol.
B. propan-1-ol and propan-2-ol.
C. methanol and ethanol.
D. propan-2-ol and butan-2-ol.
Answer D.

3. Conclusion

Currently chemistry experimental exercises are not used a variety of teaching chemistry in high school by teachers and students because the existing resource are not as rich as other types of exercise. The reason is the complexity of content exercise that associated with the experiment and often used experimental images and simulation experiments to illustrate. Above are some illustration applications to design for chemistry experimental exercises, this way, teachers can design for much more, meeting the needs of teaching chemistry in the direction of development thinking and training practical skills in high school [6,7].

Competing Interest

The authors declare no competing financial interest.
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References


[5] Scheele (1774) "Om brunsten, eller magnesia, och dess egenskaper" (On manganese or magnesia, and its properties), Kongliga Vetenskaps Academiens Handlingar (Proceedings of the Royal Scientific Academy [of Sweden]), 35: 89-116. On pages 93-94 (paragraph 6), "Med den vanliga Salt-syran." ([Reactions of manganese dioxide with the standard salt-acid [i.e., hydrochloric acid]], Scheele describes a gas (chlorine) that was produced when he reacted manganese dioxide with hydrochloric acid. Further experiments with chlorine appear in paragraphs 23-26, pages 105-110.


[8] This experiment has been reproduced from Practical Chemistry: http://www.practicalchemistry.org/standard-techniques/generating-collecting-and-testinggases, 52, AR.html.


